CHAPTER 8

SYNTHESIS

8.1 Introduction

The principal objective of my study was to determine the short-term impact of gaps and clusters silviculture on the population size, survival and spatial organisation of some insectivorous birds in a continuous forest. A secondary aim was to describe and evaluate the implications for forest management and recommend measures to help ensure the persistence of these species in forests used for producing wood. I achieved these goals by monitoring the responses of individual birds to one episode of gapping in each of two plots, which removed substantial parts of some of their home ranges. This used a BACI approach (Chapter 2) to provide new data on the resilience of some resident and migratory insectivores to habitat loss and modification (Chapters 4-7). The responses of each study species to gaps and clusters logging are summarised in Table 8.1. A project of this nature has not been undertaken previously in eastern Australia.

In this chapter, I put forward hypotheses to account for the observed responses of the study species to logging. I then discuss my interpretation of these responses in the context of three important concepts in applied ecological research: statistical significance, power of statistical tests, and the Precautionary Principle. I also consider other potential constraints to my interpretation of bird responses to the logging experiment. I then review the implications of the study's results for sustainable forest management and provide recommendations to help conserve biological diversity in forests used to produce wood. Finally, I supply a set of directions for future research.

8.2 Accounting for bird responses to logging

8.2.1 The living space hypothesis

The contrasting patterns of response to logging that I found in the study species appear to reflect fine-scale differences in their microhabitat preference, foraging ecology and physiology. These patterns embodied three levels of impact: low (Eastern Yellow Robins and White-browed Scrubwrens), intermediate (Yellow-throated Scrubwrens and Rufous Fantails), and high (Pale-yellow Robins and Spectacled Monarchs).

Eastern Yellow Robins and White-browed Scrubwrens did not change home range overlap or location, nor avoided gaps or thinned forest but did modify their foraging behaviour (Table 8.1). Both species are habitat generalists that readily utilise disturbed, open forest habitats (Marchant 1985; Smith 1989; Huggett 1994a,b; Zanette 1999). Eastern Yellow Robins pounce on prey on the ground from low perches and are favoured by increases in bare ground, logs and stumps that occur after logging (Chapter 5). Their flexible foraging strategy can include hopping over bush garden beds, paths and lawns and snatching spiders from perches on the brick walls and verandah railing of houses (pers. obs.). White-browed Scrubwrens glean invertebrates from low shrub and ground surfaces by probing into dead leaf rolls, grass clumps and bark substrates and actively flicking leaf litter aside (Chapter 3). They forage under dense cover and at exposed sites such as walking trails, log dumps and bush gardens. Their small body size allows them to forage in the confined spaces of woody debris piles, fallen dead debris and piles of bark. Norwood *et al.* (1995) observed individuals foraging along the edges of large (1.5-15 ha) gaps in West Australian jarrah forest. Both species can breed in open and thickly vegetated habitats, with White-browed Scrubwrens building nests in dense grass, often adjacent to cleared sites (Chapter 3).

These attributes may allow Eastern Yellow Robins and White-browed Scrubwrens to survive relatively unaffected in gapped forest, where open areas exist in a matrix of retained vegetation. They did not vacate newly gapped plots for control plots (Chapter 4). Eastern Yellow Robins increased the size of their home ranges after logging (Chapter 5). The ability of both species to cope with change wrought by the sudden loss of parts of their home ranges and their opportunistic use of novel microhabitat left after logging (Chapters 5 and 6) augers well for their future in continuous forest landscapes used for wood production. However, increases in the amount of edge created by gapping and thinning might lead to reduced breeding success through increased predation of nests and fledglings. There may also be intensified intraspecific competition for nest sites and territories. Clearly, further work is needed to assess these possibilities.

Logging had an intermediate impact on the home range and habitat use dynamics of Rufous Fantails and Yellow-throated Scrubwrens. Rufous Fantails foraged in the outer parts of newly established gaps and along gap edges (within 22 m of retained forest) while Yellow-throated Scrubwrens foraged along the immediate gap edge (at no more than 14 m from retained forest) (Table 8.1). These peripheral sites contained woody debris piles that offered new foraging opportunities for some individuals of both species. Both species also used thinned forest to a limited extent. Yellow-throated Scrubwrens re-established their home ranges in retained forest at similar sizes to those that they held before logging (Table 8.1).

A generalist lifestyle and flexible foraging strategy might help explain the Rufous Fantail's inclusion of these peripheral sites into their home ranges after logging. Rufous Fantails forage throughout the ground, lower and middle layers of moist forests, using a range of prey detection and capture techniques (Chapter 3). They also utilise drier slopes and ridges, especially where past logging has produced patches of dense shrubs, small trees and debris piles. Individuals often follow other ground- and shrub-foraging birds, presumably to increase their prospects of detecting prey (Hindwood 1937; Holmes 1973; Cameron 1975). Yellow-throated Scrubwrens are habitat specialists that prefer to forage in moist leaf litter and along fallen logs under dense lower and mid-canopy cover with adequate connection to riparian forest where they nest (Chapter 3). However, they also forage along the exposed edges of old log dumps, logging trails and well-used walking tracks such as in parts of Dorrigo National Park in northern NSW (pers. obs.; Howe *et al.* 1981). I observed a pair of *S. citreogularis* foraging within a 20 m-wide and 580 m-long corridor of tall *Banksia* and *Acacia* woodland, bordered on both sides by extensive pasture land within a matrix of rainforest and woodland remnants on the fragmented Dorrigo Plateau.

These features suggest that Rufous Fantails and Yellow-throated Scrubwrens may be able to persist, at least in the year immediately after logging, in gapped forests, as long as connective links have been maintained with their core breeding habitat in riparian and lower slope forest. Prospects for their longer-term persistence in gapped forest are, however, less clear. Of particular concern would be the ability of both species to successfully reproduce and recruit new birds into their breeding populations in these forests.

Newly gapped forest may be unattractive to birds that appeared to be most affected by the logging trials - Pale-yellow Robins and Spectacled Monarchs. Both species avoided gaps and foraged in some (*T. capito*) or very few (*M. trivirgatus*) of the newly thinned areas (Table 8.1). Pale-yellow Robins changed home range location and held smaller home ranges with possibly increased overlap after logging (Table 8.1). Both species are habitat specialists that require dense lower and mid-canopy cover, low shrubs with suitably shaped forks in which to build nests (Chapter 3; Boles 1988), and a high degree of connection to riparian forest, which contains their core breeding habitat (Chapters 5 and 7; Frith 1984; Chapman & Harrington 1997). *T. capito* often uses fallen logs to pounce on prey on moist ground (Chapter 5). Both species may favour darker tracts of forest where the risk of predation may be less than in more exposed sites (Chapman & Harrington 1997) and may consequently avoid open space such as clearfelled gaps.

These are plausible reasons for the observed post-logging shifts in *T. capito* home ranges away from gaps and into adjacent retained forest. They may also help to account for the location of Spectacled Monarch home ranges in creeklines after logging in the E2 Plot, although more data are needed to test this contention. Pale-yellow Robins and Spectacled Monarchs may have perceived new gaps as hostile (*sensu* Lima *et al.* 1987) space, where potential food rewards may have been outweighed by predation risks. I contend that this rigidity in response to logging may not favour the longer-term persistence of *T. capito* and *M. trivirgatus* in gapped forest unless significant tracts of riparian and lower slope forest are retained in each logging cycle (Section 8.4). Ongoing monitoring of the survivorship, breeding success and home range and habitat use dynamics of these populations in my plots is needed.

Studies of Ovenbirds *Seiurus aurocapillus* and Kentucky Warblers *Oporornis formosus* in North American temperate forests lend some support to my hypothesis of logging response. Both species forage for invertebrates in moist leaf litter on the floor of deciduous forests (Gibbs & Faaborg 1990; Van Horn *et al.* 1995; Burke & Nol 1998) in a manner similar to *S. citreogularis* and *S. frontalis*. Ovenbirds are habitat specialists and have been found to be particularly sensitive to breaks in forest cover created by logging and other activities (Probst *et al.* 1992; Wenny *et al.* 1993; Yahner 1993). Individuals held significantly fewer territories near forest edges than in forest interiors in a contiguous Vermont (USA) forest (Ortega & Capen 1999). Kentucky Warblers, however, are habitat generalists that readily forage and breed in natural and logged forest, providing that dense ground cover is available (Hayden *et al.* 1985; Wenny *et al.* 1993).

8.2.2 Ancillary hypotheses

Some other factors might help account for the observed patterns of bird response to logging in my study. I contend that these supplement the main case presented in Section 8.2.1. They include population density, social structure, resource quality and distribution, and local variation in vegetation structure and floristic composition.

Variation in the density of animal populations can influence the size and shape of home ranges (Schoener 1968, 1981). Other than Rufous Fantails, each of my study species occurred at low-moderate densities in the logged and unlogged plots (Chapter 4). This may have placed less pressure on space and allowed individuals to alter the location but maintain the size of their home ranges after logging, without increasing overlap with the ranges of neighbours.

The social structure of animals can also influence the location, shape and size of their territories and home ranges (Brown 1964, 1975; Smith *et al.* 1998; Jansen 1999). Animals living in groups may maintain larger or multi-cored home ranges than animals living singly, as group members defend larger foraging areas or patches of richer habitat quality (Kenward & Hodder 1996; Jansen 1993, 1999). The maintenance of a larger home range by the AMMF1 White-browed Scrubwren group in E2 Plot relative to birds of this species that lived as simple pairs may exemplify this influence.

Changes to patterns of availability, quality and distribution of food that may have occurred after logging might have influenced the location and size of home ranges of Pale-yellow Robins, Yellow-throated Scrubwrens, Rufous Fantails and Spectacled Monarchs. The home ranges of these species were centred on sites of high quality breeding habitat such as dense Lawyer Vine *Calamus muelleri* thickets, *Cissus* vine clumps and Bangalow Palm groves (Chapters 5-7). Adjoining habitat such as dense patches of shrub regrowth, old debris piles and *Lantana camara* thickets provided foraging space for these species. Logging clearly reduced the availability of these habitats, increased the penetration of light and heat into the forest, and therefore probably reduced the amount of invertebrate prey present at these sites. This may have contributed to these species' total or partial avoidance of gaps and increased use of clusters and other tracts of retained forest. In contrast, the ability of Eastern Yellow Robins and White-browed Scrubwrens to utilise a variety of resources seemed to allow them to maintain home range structure after logging (Chapters 5 and 6).

Variation in the structure and floristic composition of temperate eucalypt forest can influence the use of space by insectivorous birds (see Abbott & Van Heurck 1985; Howe 1986;

Recher *et al.* 1996; Section 2.5). In my study, local variation in vegetation structure and floristic composition might have exerted some influence over the location of home ranges of the study species. Slope, ground stratum cover, lower stratum cover, and mid stratum height were the most important variables in distinguishing between the plots on the basis of vegetation structure (see Section 2.5). The range centres of Pale-yellow Robins, Yellow-throated Scrubwrens, Rufous Fantails and Spectacled Monarchs occurred in areas of dense lower and mid stratum cover near drainage lines. Groves of Bangalow Palm, Lawyer Vine and other rainforest plants were a distinctive feature of these sites and were favoured as nest sites by these species. Eastern Yellow Robins and White-browed Scrubwrens were less discriminating in their choice of nest sites and foraging domains, often preferring more open areas away from creeks. More work is clearly needed to determine the role of vegetation structure and floristics in bird use of space in the research plots (see Section 8.5).

8.3 Interpretation of bird responses to logging

Statistical significance, power of statistical tests and the Precautionary Principle

An important consideration in the interpretation of logging impacts on fauna is the degree of confidence with which one draws conclusions of effect or no effect (see Lindenmayer & Possingham 1995; Calver *et al.* 1999a). This is defined in the context of the level of statistical significance of test results, conventionally set at 95% ($\alpha=0.05$). The ability of statistical tests to detect an effect at this level is influenced by the sample size and concomitant power of the test (see Cohen 1988; Calver *et al.* 1999a,b; Goodall 1999). In this sense, the small size of my data sets (see *Other considerations* below) will have reduced the power of my statistical tests to detect logging impacts. Calver *et al.* (1999a) suggested increasing the power of tests to detect impacts by relaxing the significance level to 0.2. However, this can increase the probability of committing a Type I error (ie. falsely concluding that there has been an impact) (Calver *et al.* 1999a). Goodall (1999) advised that estimates of the magnitude of an effect, irrespective of its statistical significance, should be part of the impact assessment process. Where possible, I provided these estimates with the results of statistical tests of bird responses to logging, especially those that approached the 0.05 level of significance (Chapters 4-7).

The Precautionary Principle advocates adoption of measures to safeguard natural systems where there is the threat of serious or irreversible damage from a specific disturbance, despite the lack of full scientific certainty of the perturbation's potential impacts (Deville & Harding 1997). Goodall (1999) has suggested that the principle should be re-worded to require a consideration of the probable effects of the disturbance since, in practice, full scientific certainty of potential impacts on natural systems usually cannot be obtained. This still places the onus on the proponent to prove that the activity will not affect the environment or that any effect will be within acceptable limits (Goodall 1999).

In my study, adopting the Precautionary Principle at $P<0.10$ would lead to conclusions of logging impact despite failure to reject null hypotheses at the conventional 0.05 level. This would have resulted in conclusions of significant decreases in population size ($P=0.089$) and survivorship ($P=0.070$) in Yellow-throated Scrubwrens (see Tables 4.2 and 4.4), increases in home range overlap in Pale-yellow Robins ($P=0.065$) and Spectacled Monarchs ($P=0.081$) (see Tables 5.3 and 7.2), and a reduction in home range size in White-browed Scrubwrens ($P=0.081$) (see Table 6.1). In these cases I elected to minimise Type I error by adhering to the 5% significance level, despite the risk of committing a Type II error (ie. falsely concluding that there had not been an impact) (see Kavanagh 2000 for the use of the $P<0.10$ approach in the evaluation of logging impacts on Greater Gliders in southern NSW). Therefore, I accepted the null hypotheses of no significant impact but recommend further research and monitoring (Section 8.5). From a conservation standpoint, however, a reasonable precautionary approach is that it seems likely that these species are affected by logging. Both viewpoints offer alternative ways of considering the impacts of the logging trials on the study species. Further work is clearly needed to confirm or reject these impacts and develop appropriate management strategies (Sections 8.5 and 8.6).

Other considerations

There are three other potential constraints to my interpretation of bird responses to logging. First, the labour-intensive nature of colour-banding and monitoring the movement of individual birds meant that small sample sizes were obtained, especially for the two migratory species. This limited the number of home ranges of individuals that could be monitored before and after logging in each plot. Therefore, I may have obtained only a partial indication of the nature of logging impacts on the study species.

Second, there was a clear need for more replication of the logging trials and for the continuation of monitoring in the logged plots over the longer-term (Chapter 4). Forest ecosystems are inherently variable between seasons and years (Mac Nally 1996; Lindenmayer 1997) and, as Lindenmayer & Recher (1998) and Recher (1998) recommend, should therefore be monitored over several years and at a number of sites. Previous experimental attempts (see Margules 1992; Burrows *et al.* 1993, 1994; Margules *et al.* 1998; Craig 1999) at assessing logging impacts on avifauna may have suffered from a similar lack of replication and longer-term monitoring (see Recher 1998).

A third limitation was that I did not investigate the impact of logging on breeding success and recruitment in the six study species. These species may survived the initial round of logging but may not be maintained if breeding fails in the following seasons. Rowley & Brooker (1987) found that Splendid Fairy-wrens *Malurus splendens* survived the firing of West Australian heathland but experienced breeding failures over the longer-term and subsequent population declines. Therefore, in my case, there is a need to study the breeding dynamics of the study species in the logged plots over several seasons after logging (Section 8.5).

8.4 Implications and recommendations for sustainable forest management

Current management of publicly-owned native forest in Australia seeks to achieve two principal objectives: the commercial production of wood, and the conservation of biological diversity (Chapter 2). Implementation of these goals requires adequate and accurate resource information to guide sound decision-making and strategic resource planning. There is an ever-pressing need for this information to be drawn from the results of rigorous field studies of logging impacts (see Davey & Norton 1990; Lindenmayer *et al.* 1998), despite the drawbacks of some of the methodologies of these studies (see review in Calver & Dell 1998b).

The results of my study have a number of important implications for the sustainable management of regrowth eucalypt forests. First, each species studied showed varying degrees of resilience to logging. Habitat generalists appeared to be more resilient than habitat specialists, which experienced marked changes to their patterns of home range and habitat use. These findings suggest that small-scale gapping in a continuous forest landscape may not adversely affect Eastern Yellow Robins and White-browed Scrubwrens, providing that sufficient adjoining forest is retained in each cutting cycle. Rufous Fantails and Yellow-throated Scrubwrens might also not be negatively affected by gapping (at least not in the short-term), although more data is needed before this can be confidently concluded. However, by impairing the use of forest space by two habitat specialists (Pale-yellow Robins and Spectacled Monarchs) and reducing the availability of their preferred foraging habitat, gapping may compromise their ability to persist beyond the first year after logging in each logged plot. A consequence of gapping for *T. capito* and *M. trivirgatus* may be an increased potential for local population decline over time through reduced breeding success and recruitment, although this needs further investigation. This possibility calls for specific precautionary measures to be taken in the planning and implementation of future logging operations (see below).

Second, my work illustrated the importance of considering the influence of scale of impact on bird responses to logging. A much greater impact on bird survival, population size and use of space may have occurred if, for example, 5-10 ha gaps were created instead of the 0.64 ha gaps of my study. With larger gaps, entire home ranges of individual birds of these and other species would be likely to have been removed, rather than only parts of ranges as occurred in my trials. Birds such as White-browed Scrubwrens and Pale-yellow Robins with smaller home ranges than the other study species may be especially adversely affected by larger-scale gapping. Other ground-foraging species such as the Logrunner, Chowchilla, Black-breasted Button-quail, Noisy Pitta, Russet-tailed Thrush and Bassian Thrush *Z. lunulata* may also be negatively affected by this larger-scale loss of habitat. Conversely, small-scale gapping may have little effect on these species, primarily because of their larger home ranges than those of my study species (e.g. mean 2.33 ha for Chowchillas in tropical vine forest on Atherton Tablelands, North Queensland - Jansen 1993, 1999; mean 4 ha for Black-breasted Button-quails in subtropical vine forest remnants, south-east Queensland - Smith *et al.* 1998). Further work is clearly needed to assess these possibilities.

Third, my study demonstrated the importance of riparian buffers, clusters and other tracts of retained forest in a commercially logged landscape. These zones effectively absorbed the impact of gapping on the habitat specialists by accommodating birds displaced by logging. This emphasises the value of retaining riparian vegetation in timber harvesting operations (see also Norwood *et al.* 1995; Craig 1999). There is, however, a need to integrate the retention of forest across gullies, midslopes and ridges rather than simply view riparian buffers as corridors for animal movement or as repositories for animals sensitive to activities such as logging and agricultural land clearing (see Lindenmayer 1993; Claridge & Lindenmayer 1994). This integrated approach was implicit in my experimental design and should be adopted in future gapping operations.

Fourth, I have identified the components of each species' ecology that seemed important in influencing their persistence and response to logging in the experimental plots. This is new information, which can be used to ensure adequate consideration is given to the protection of these components, wherever possible, in the planning of future logging operations. Of particular value would be the retention of some woody debris piles left unburnt after logging as foraging microhabitat for Eastern Yellow Robins, White-browed Scrubwrens, and a number of other birds and reptiles. These piles did not cover more than 10-20% of the surface area of gaps. Although these piles inhibited eucalypt regeneration in these parts of the gaps (pers. obs.), the rapid rates of regrowth of eucalypt forests on the NSW north coast (King 1985) and the relatively rapid decay of debris piles in these constantly moist conditions (Smith *et al.* 1995) would probably compensate for any initial loss of forest regenerative capacity caused by the retention of woody debris piles. Large (>40 cm diameter and >2 m length) fallen logs should be retained *in situ* as foraging habitat for both scrubwren species, Pale-yellow Robins and other fauna.

A fifth implication for forest managers is that the different home range and habitat use responses of my study species illustrate some of the variability that exists among Australian temperate forest birds in their resilience to logging (see Recher 1998). This emphasises the species-specific nature of bird responses to small-scale gapping in continuous forest and cautions against the use of my results to predict the responses of other bird species in other forest landscapes. Also, there may be other bird species that are more sensitive to logging and associated disturbance, which leave or do not return to logged sites. Species dependent on tree hollows for nesting and shelter such as the large forest owls, parrots, cockatoos and treecreepers may be particularly disadvantaged by clearfelling to create gaps. Other species may be more tolerant of logging such as fairy-wrens, Red-browed Finch, Grey Shrike-thrush, and Grey Butcherbird.

Other management implications concern bird use of thinned forest and the time required for gapped sites to become suitable for the habitat specialists. The use of some parts of newly thinned areas by gap-sensitive species (e.g. *T. capito* and *M. trivirgatus*) may suggest that light thinning might not adversely affect these species' short-term persistence in forest that contains a matrix of small gaps and selectively logged and unlogged areas. Alternatively, these birds may only use thinned areas if part of their home ranges includes substantial tracts of unlogged habitat. The species that showed intermediate sensitivity to the logging trials (*R. rufifrons* and *S. citreogularis*) may be more tolerant of thinning operations, especially those conducted at moderate intensities, than *T. capito* and *M. trivirgatus*. Further study of the effects of variable intensity thinning on these species should be undertaken in the study area (Section 8.5).

My study indicates that dense riparian forest is the core breeding and foraging habitat of each of the habitat specialist species (*T. capito*, *S. citreogularis*, *M. trivirgatus*) and the Rufous Fantail (Chapter 3). However, I have also shown that some Yellow-throated Scrubwrens and Rufous Fantails can forage in younger (at least 6 year-old) moist eucalypt regrowth with a dense, low-medium (2-8 m) understorey, providing that adequate linkage exists with riparian and lower slope forest. In the fast-growing NSW north coast forests, these requirements suggest that gaps created in my study may be able to provide low quality foraging habitat for Yellow-throated Scrubwrens and Rufous Fantails by approximately 2003 and 2004, respectively. Provision of higher quality foraging and breeding habitat (ie. tree canopies, structurally and floristically diverse shrub and ground layers, decaying large logs) for the habitat specialists and Rufous Fantails may require at least a further 30-40 years. Thus, it may be at least 2027-2028 before gaps could support breeding populations of these species.

This has important long-term implications for the planning and implementation of subsequent cycles of 80 m-wide gapping that are part of the original gaps and clusters model (Chapter 2). Also implicated are integrated harvesting operations that are currently licenced (in north-east NSW forests) to establish small (maximum width of 50-70 m) gaps where suitable stand conditions exist. According to this model, the second cut would be scheduled for 15 years from the first gapping round (ie. 2012-2013). Of course, sufficient areas of merchantable forest must be available prior to any logging. Forest retained as clusters in the first round of gapping could be cut in the second round, *providing* that regenerating first round gaps could function as clusters by this time, ie. they could provide foraging and preferably some breeding habitat for the habitat specialists. Therefore, this second round of gapping would remove 21-22+ year-old regrowth, since this vegetation was at least 6 years old at the time of the first cut. The third cut would be scheduled for 30 years from the initial round (ie. 2027-2028). In areas that have been heavily cut over, gaps and clusters silviculture may not be a commercially viable wood production option. It may be a form of logging that is more suited to an even-aged forest structure such as plantations where stands of fast-growing, commercial tree species are intensively managed for high yield.

On the basis of these considerations, I put forward a set of preliminary recommendations to assist forest managers to strategically plan future logging operations in moist regrowth eucalypt forests. These are:

1. Retain connective forest links across the local and regional forest landscape, especially riparian buffers, moist lower slopes adjoining riparian zones, clusters, and strips that join adjacent forested catchments (connection corridors).
2. No more than 25% of available forest cover in each plot should be removed in one 15 year cutting cycle (80 m wide gaps) or one 10 year cutting cycle (50 m wide gaps).
3. Harvest plans for proposed gaps and clusters operations should include measures to ensure the protection and recruitment of habitat trees in clearfelled forest at a density and spacing consistent with current prescriptions in the North East NSW Regional Forest Agreement study area.
4. Pre-logging surveys and biodiversity monitoring programs should map the density and distribution of other essential habitat components in areas proposed for gapping and thinning, including dense patches of shrub cover, large hollow logs (>40 cm diameter and >2 m length), bangalow palm groves, vine tangles and woody debris piles; measures to protect these components should be incorporated into harvest plans (see points 5 and 6 below).
5. Retain some piles of woody debris (ie. avoid burning them) in and around the edges of gaps to provide foraging microhabitat for Eastern Yellow Robins, White-browed Scrubwrens, Yellow-throated Scrubwrens, Rufous Fantails and other fauna.
6. Wherever possible, retain large fallen logs *in situ* (see Lindenmayer *et al.* 1999) to provide foraging microhabitat for *S. citreogularis*, *S. frontalis* and *T. capito* and other ground-foraging birds and mammals, reptiles and invertebrates.

7. Harvest plans for gaps and clusters proposals should also include minimum standards for fauna refuge area and design at plot, compartment and landscape scales; these may require that at least 25% of the net harvestable area in each compartment subject to gapping be reserved from logging, and a minimum 25% of the total area of each major habitat present in the compartment should remain unlogged, which may include riparian buffers, flora reserves and preserves but not steep or inaccessible terrain (NSW Ministerial Advisory Committee 1996).

8.5 Directions for future research

There are several important lines of scientific inquiry that should be pursued if the medium- and longer-term impacts of gaps and clusters logging on the study species and other fauna are to be elucidated. A collaborative approach to this work is recommended, involving State Forests of NSW, NSW NPWS, universities, and avian field study groups such as Birds Australia and the North-east NSW Bird Banders. This should optimise the use of available resources, especially scientific expertise, local knowledge, labour and capital. Publication of results in peer-reviewed journals should be a major objective of this collaboration. Specific directions for this research include:

1. Monitor the size, survival, breeding success and recruitment of colour-banded populations of each study species in each research plot for at least 10 years after my logging trials. Increase the number of colour-banded individuals of each study species in all plots.
2. Monitor changes in home range (size, overlap, shape and location) and microhabitat use in each study species for at least 10 years after my logging trials.
3. Plan further trials over at least 5 years to compare the logging responses of other species (e.g., Logrunner, Bassian Thrush *Zoothera lunulata*, Russet-tailed Thrush, Eastern Whipbird, Golden Whistler, Green Catbird, Lewin's Honeyeater, Noisy Pitta, Large-billed Scrubwren, Brown Gerygone and Brown Thornbill) with those of the study species in different sites in production forests based on, or adapted from, the methods used in my study. Ensure that migratory species are monitored before and after logging. Trials should preferably be replicated over a range of gap sizes from 0.5-5 ha (NSW Ministerial Advisory Committee 1996) and encompass a range of thinning intensities in order to provide experimental variation (see Lindenmayer & Recher 1998) and determine

possible thresholds of gapping tolerance among the study species. Smaller gaps currently being created in standard logging programs on the NSW north coast could also provide experiments in which data collection, analysis and management synthesis could be interlinked (see Lindenmayer & Franklin 1996; Lindenmayer 1997).

4. Investigate the role of regenerating gaps and thinned zones in the provision of microhabitat for each study species. Determine the time since logging that gaps can provide foraging and breeding habitat for the habitat specialists - Pale-yellow Robin, Yellow-throated Scrubwren and Spectacled Monarch.
5. Quantitatively assess the relative importance of the main components of microhabitat of Pale-yellow Robins, Yellow-throated Scrubwrens, Rufous Fantails and Spectacled Monarchs that may influence their recolonisation of regenerating gaps and longer-term persistence in gapped forest. Of particular importance are foraging substrates, nest sites, large fallen logs, and dense shrub regrowth.
6. Investigate the role of variation in floristic composition in influencing bird use of regenerating gaps and thinned zones in the logged plots. Emphasis could be placed on comparing canopy, sub-canopy and ground arthropod abundance, distribution and species diversity (see Recher *et al.* 1996; Laven & Mac Nally 1998; Majer *et al.* 2000) in logged and control plots.
7. Include the research plots in a network of State and/or national biodiversity impact monitoring and research to optimise the value of my findings in harvest planning, biodiversity conservation and community education (see Brown 1998).
8. Further research should address the behavioural responses of birds to gaps such as gap-crossing and corridor movement, perhaps adapting experimental approaches used by Desrochers & Hannon (1997) and St. Clair *et al.* (1998); other edge interactions such as predation and competition for nest sites and mates in which each edge of a gap could be treated as a replicate (R. Loyn pers. comm.), thus substantially increasing the level of experimental replication; age- and gender-related differences in gap tolerance among study species and how these vary over time; identification and importance of core foraging areas/activity centres in individual home ranges of study species; and the role of changing vegetation structure and floristic composition of gaps in providing new foraging and breeding habitat for the study species as well as invasive species and predators.

8.6 Conclusions

I conclude that there is insufficient evidence from my short-term study to answer the question posed in Chapters 1 and 2, namely, does gaps and clusters silviculture achieve the 'dual imperative' of biodiversity conservation and wood production. There was, however, preliminary evidence that Eastern Yellow Robins and White-browed Scrubwrens are reasonably resilient to the creation of small gaps in a continuous forest landscape. Rufous Fantails and Yellow-throated Scrubwrens appeared to show a degree of tolerance to gapping, although more data are needed. Pale-yellow Robins and Spectacled Monarchs are more specialised in their use of habitat and avoided gapped areas. These contrasting responses illustrate the importance of studying logging impacts on individual species.

Perhaps the question should be re-phrased to ask what combinations of logging techniques are needed by different faunal assemblages in specific areas of production forest. This avoids a potentially myopic focus on attempting to prescribe one particular silvicultural system to accommodate a diverse range of forest biota, some of which may be negatively affected by site-intensive operations such as gapping and others which may be favoured by this form of logging. An integrated mix of selective logging, gaps and clusters, some hardwood plantations and reserved areas seems a more appropriate approach to meeting wood production and fauna conservation requirements in NSW north coast forests. This requires careful planning at the landscape level to avoid fragmenting these biologically significant forests and a clear commitment to ongoing forest research and monitoring programs.

Table 8.1 Summary of the short-term responses of six insectivorous bird species to gaps and clusters logging in regrowth moist eucalypt forest near Coffs Harbour, NSW mid-north coast. HR=home range.

Study species	Response to gaps and clusters logging[1]						
	Population size	Change in HR size	Change in HR overlap	Change in HR location	Avoidance of gapped areas	Avoidance of thinned areas	Change in foraging behaviour
Eastern Yellow Robin	no change	increased	no	no	no	no	yes
Pale-yellow Robin	no change	decreased	no (possible increase)[3]	yes	yes	partial	generally no
Yellow-throated Scrubwren	no change	no	no	yes	yes, except gap edges	no, but infrequent use	yes
White-browed Scrubwren	no change	no (possible decrease)[2]	no	no	no	no	yes
Rufous Fantail	no change	no	no	possibly[5]	yes, except gap edges	no, but infrequent use	partial
Spectacled Monarch	no change	no	no (possible increase)[4]	possibly[5]	yes	very limited occasional use	partial

[1] no change = no significant change detected at $P=0.05$ (95% confidence interval)
[2] possible decrease = as suggested by $P=0.081$ result (Chapter 6)
[3] possible increase = as suggested by $P=0.065$ result (Chapter 5)
[4] possible increase = as suggested by $P=0.081$ result (Chapter 7)
[5] possibly = individuals of these species avoided all newly created gaps (*M. trivirgatus*) or only used gap edges (*R. rufifrons*) but a lack of pre-logging data does not allow a conclusion of change in HR location due to logging to be unequivocally made (Chapter 7)

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